MRL-TN-467

AR-003-049

(12)

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MRL-TN-467

AD A127528

PYROTECHNIC SWITCH

G.D. Holt

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SEPTEMBER 1982

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ABSTRACT

A pyrotechnic switch which is non-conducting before actuation and fully conducting after actuation has been developed. The switch utilises the principle that a pyrotechnic composition containing oxides and a fuel has a very high electrical resistance prior to ignition. However, after ignition the oxide is converted to a low resistance metal slag which makes contact between two points in a switch.

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SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED

DOCUMENT CONTROL DATA SHEET

REPORT NO.	AR NO.	REPORT SECURITY CLASSIFICATION
MRL-TN-467	AR-003-049	Unclassified

TITLE

PYROTECHNIC SWITCH

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REPORT DATE	TASK NO.	SPONSOR
September, 1982	ARM 80/220	Army

CLASSIFICATION/LIMITATION REVIEW DATE

CLASSIFICATION/RELEASE AUTHORITY
Superintendent, MRL Physical Chemistry Division

SECONDARY DISTRIBUTION

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KEYWORDS
Arming device
Delay elements (explosive)
Switches
Pyrotechnic Switch

COSATI GROUPS 1901

ABSTRACT

A pyrotechnic switch which is non-conducting before actuation and fully conducting after actuation has been developed. The switch utilizes the principle that a pyrotechnic composition containing oxides and a fuel has a very high electrical resistance prior to ignition. However, after ignition the oxide is converted to a low resistance metal slag which makes contact between two points in a switch.

CONTENTS

PYROTECHNIC SWITCH

1. INTRODUCTION

A simple pyrotechnic switch was designed to arm an electrical impact firing circuit for a propellant launched pyrotechnic store. The concept for the switch called for flame ignition of a safety delay followed by the electrical arming of the firing circuit outlined in Fig 1. The arming function of the switch was designed to be initiated from hot gases which propel the store to flight. During flight, the pyrotechnic train within the switch burns, giving a safety delay, followed by closing of the electrical contacts. The switch had to be robust to survive the planned use of the store and any accidental shock, sudden movement or static electrical hazard.

2. DEVELOPMENT OF THE SWITCH

The design of a pyrotechnic switch was based on the fact that the initial mixture of metal oxides and fuel are non-conducting. However, they can be readily converted to a highly conductive metalic slag by a simple pyrotechnic reaction. This concept can be used to close two electrical contacts and thus arm a firing circuit.

To satisfy the design requirements, a pyrotechnic fuse train utilising exothermic reactions resulting in a conducting solid was investigated. Reliability of ignition within the train, incorporation of a time delay, electrical contact points, materials of construction, composition of pyrotechnic material, ease of manufacture and handling properties were studied.

3. COMPOSITION EVALUATION

A typical exothermic reaction occurs with a stoichiometric mixture of a metal oxide and a fuel such as boron. For example, the following reaction at atmospheric pressure can be considered typical.

$$2B + 3PbO \rightarrow B_2O_3 + 3Pb \qquad \Delta H = -6.11 \times 10^5 J$$

$$\uparrow$$

non-conducting conducting

The heat generated from the reaction will raise the temperature of the reaction products to a high level. If the heat of reaction is too great, the metallic products (lead in this example) may vaporize and subsequently condense in areas other than across the contact pins, thereby failing to produce a satisfactory electrical contact.

To utilize this type of reaction at atmospheric pressure it is important that the conducting product (the metal) does not vaporize. In the given example the temperature is limited to about 1700°C by the boiling point of the products.

The first switch considered utilized boron/lead oxide (B/PbO) composition, pressed onto the contact pins of a glass-metal seal. The boron/lead oxide composition was ignited from a 6 strand multicore delay element made from lead tube and filled with boron/barium chromate ($B/BaCrO_4$) composition. To ensure reliable ignition of the multicore, an increment of boron/barium chromate ($B/BaCrO_4$) was pressed on top. The boron/barium chromate ($B/BaCrO_4$) composition was selected due to its even burning characteristics and ignitability. Early trials using this configuration indicated that the lead released during the boron/lead oxide reaction vaporized away from the contact pins, opened vent holes through the multicore delay element and condensed well away from the contact pins. Various configurations failed to prevent this and, to overcome it, a number of alternative compositions were considered, each generally having a lower enthalpy of reaction. The metallic products from each reaction had considerably higher boiling points, while still providing a low resistance path between contact pins after reaction. The compositions tested are listed in Table 1.

The most satisfactory composition was boron/iron oxide (B/Fe_3O_4), the reaction of which proceeds as shown:

$$3Fe_3O_4 + 8B \rightarrow 4\,B_2O_3 + 9Fe \quad . \quad \Delta H = -1.93 \times 10^6 J$$

Iron has a boiling point of about 3,000°C and the above reaction proceeded with a lower heat output to produce a porous but firm, metallic slag with low electrical resistance.

4. SWITCH DESIGN

Although electrical contact between the pins was established on each occasion, inspection revealed that the metallic residue from the reaction had "kicked-back" from the base of the glass-metal seal. This effect on the residue or bed was attributed to a pressure build-up at the glass-metal seal/composition interface, forcing the products of the reaction back from the base of the switch.

To minimize this undesirable effect four small vent holes (0.8 mm dia) were drilled through the brass tube to the interface between the glass-metal seal and the composition. Any pressure build-up forward of the reaction front could then escape to atmosphere. After several trials it was found that the vent holes had eliminated any further evidence of the "kick-back" effect.

As the switch was required to be open-circuit initially, non-conducting starting materials were used in the pyrotechnic train. The initial resistance across the contact pins was found to be consistently greater than 100 k Ω. After reaction of the composition, the resistance across the contact pins was reduced to less than 0.1 Ω as shown in Table II.

Various delay times could then be implemented by different amounts of pressed composition used in the pyrotechnic train. To ensure that the pyrotechnic train retained its pressed charactertistics an interference-fit inverted copper detonator cap with a centrally drilled 2.8 mm dia hole was pressed onto the pyrotechnic train. A further increment of SFG 40 was then pressed into the cap to complete the pyrotechnic train as shown in Fig. 2.

5. PYROTECHNIC TRAIN

In order to ensure reliable ignition of the boron/iron oxide composition, a 0.150 g increment of SR92 was pressed onto the composition. As the design of the switch required it to be ignited from a flame or hot propellant gas source, two increments of gunpowder were pressed onto the top of the SR92 composition. The pyrotechnic train then consisted of SFG 40 (Gunpowder) - SR92 - B/Fe_3O_4 composition as shown in Fig 2.

Various delay times can then be achieved by varying the amount of pyrotechnic constituents used in the train. A typical arming delay of 0.10 to 0.27s can readily be achieved by varying the amount of gunpowder (SFG 40) from 0.03 to 0.10 g. A variation in SFG 40 from 0.03 g to 0.10 g resulted in the delay time increasing from 105 ms to 274 ms as shown in Table III. Longer delay times can be obtained by varying the amount of SR92 or by including a segment of multicore delay as shown in Fig. 3.

6. RESULTS

A number of switches were manufactured and tested using the design shown in Fig 3. Several compositions (listed in Table I) were considered and evaluated for their suitability. Both boron/lead oxide (B/PbO) and boron/cupric oxide (B/CuO) compositions were found unsuitable due to the problem of the released metal vaporizing during the reaction and venting away before a conducting bed could be formed across the contact pins. Close examination revealed that the metal products from each reaction had condensed around the walls and vent holes, but had failed to produce a permanent conducting bed across the contact pins.

The composition boron/barium chromate ($B/BaCrO_4$) was found to produce a strongly conducting bed. Close inspection revealed that the bed was brittle and susceptible to crumbling.

Compositions $B/BiO/Cr_2O_3$ (SR92) and B/Fe_3O_4 on reaction both formed conducting metallic beds with resistances less than 0.5 Ω, close inspection of the bed characteristics revealed that they were firm, not susceptible to crumbling, and formed a solid conducting bridge across the contact pins of the switch.

7. FINAL DESIGN OF PYROTECHNIC SWITCH

A pyrotechnic switch, which meets the requirements outlined in the introduction has been developed and tested. The compositions chosen for use in the switch are:-

(a) SFG 40 - to provide ignition of the switch from hot gases,

(b) SR 92 - priming composition for the switch composition, and

(c) B/Fe_3O_4 - switch composition

The operating time of the switch can be varied from 0.1 to 0.27 seconds by varying the amount of SFG 40 present. If a longer time delay is required, a segment of multicore delay may be inserted into the pyrotechnic train.

Filling and assembly details of both types of switch (see Figs 2 and 3) are given in Appendix A.

8. CONCLUSIONS

A reliable pyrotechnic switch has been developed which can be used as a safety arming device in an electrical circuit where a time delay is required. The switch as developed is designed to be initiate from a flame. However, this could be modified to allow ignition by other source, such as electric (bridgewire), stab, or percussion cap. The switch incorporates a pyrotechnic delay, the operational time of which can be varied depending on the choice of pyrotechnic compositions.

TABLE I

COMPOSITIONS EVALUATED

COMPOSITION	RESULT	EVALUATION
B/PbO	Lead vaporized, no bed formed.	Unsuitable
B/CuO	Copper vaporized, no bed formed.	Unsuitable
$B/BaCrO_4$	Brittle conducting bed formed.	Unsuitable
$B/BiO/Cr_2O_3$ (SR92)	Firm conducting bed formed.	Suitable
B/Fe_3O_4	Firm conducting bed formed.	Suitable

TABLE II

RESISTANCE EVALUATION OF

BORON/IRON OXIDE (B/Fe_3O_4) SWITCH

SWITCH NO.	RESISTANCE BEFORE FIRING (kΩ)	RESISTANCE AFTER FIRING (Ω)
E_1	255	< 0.1
E_2	114	< 0.1
E_3	171	< 0.1
E_4	141	< 0.1
E_5	126	< 0.1
F_1	168	< 0.1
F_2	123	< 0.1
F_3	159	< 0.1
F_4	163	< 0.1
F_5	173	< 0.1

TABLE III

TIME EVALUATION OF

BORON/IRON OXIDE (B/Fe_3O_4) SWITCH

SWITCH NO.	RESISTANCE BEFORE FIRING (kΩ)	RESISTANCE AFTER FIRING (Ω)	WT OF SFG 40 IN PYRO TRAIN (g)	TIME (ms)
B1	202	< 0.1	0.10	274
B2	154	< 0.1	0.08	152
B3	131	< 0.1	0.05	119
B4	147	< 0.1	0.03	105

COMPOSITION AND PRESSING DETAILS

1. COMPOSITIONS

I	B/Fe_3O_4 composition consisted of:	
	Black Iron oxide Fe_3O_4	85% (by weight)
	Boron (dried) B	15% (by weight)
II	SR92 composition consisted of:	
	Boron	12% (by weight)
	Chromic oxide	22% (by weight)
	Bismuth oxide	66% (by weight)
III	$B/BaCrO_4$ composition consisted of:	
	Barium Chromate	90% (by weight)
	Boron	10% (by weight

Each composition prepared by hand mixing the ingredients together and then passing four times through a BS Sieve No 60.

2. PRESSING DETAILS

I. WITHOUT MULTICORE DELAY (Fig 2)

a. B/Fe_3O_4 composition added in two increments, each of 0.125 g and pressed to 14 MPa.

b. SR92 composition then added in one increment of 0.150 g and pressed to 14 MPa.

c. SFG 40 then added in two increments, the first increment of 0.01 g pressed to 14 MPa followed by an inverted copper detonator cap with centrally drilled 2.8 mm hole, then the remaining SFG 40 (0.04 g) and pressed to 14 MPa.

II WITH MULTICORE DELAY (Fig 3)

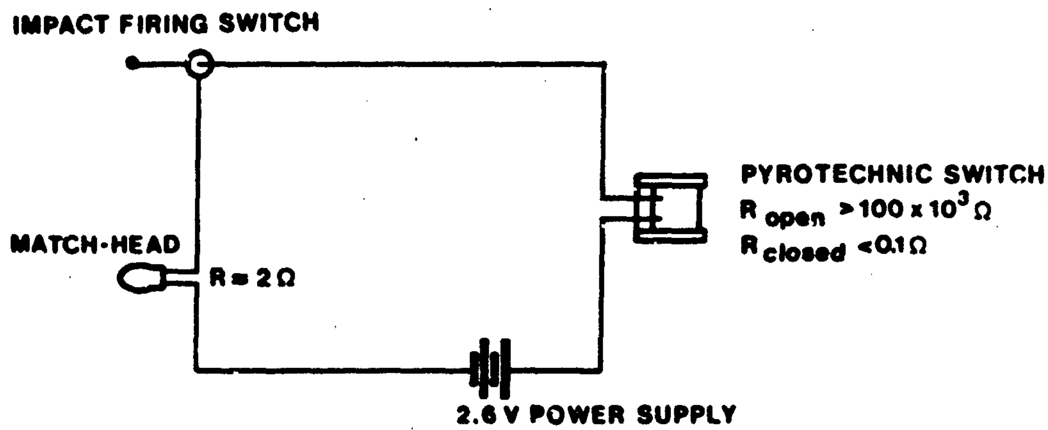
a. B/Fe_3O_4 composition added in two increments, each of 0.125 g and pressed to 14 MPa.

b. SR92 composition then added in one increment of 0.150 g and pressed to 14 MPa.

c. Multicore delay element then added and pressed to 14 MPa.

d. $B/BaCrO_4$ composition then added in one increment of 0.20 g and pressed to 14 MPa.

e. 0.05 g of SFG 40 then added in two increments, the first increment of 0.01 g, pressed to 14 MPa followed by a inverted copper detonator cap with centrally drilled 2.8 mm hole, then the remaining SFG 40 (0.04 g) and pressed to 14 MPa.



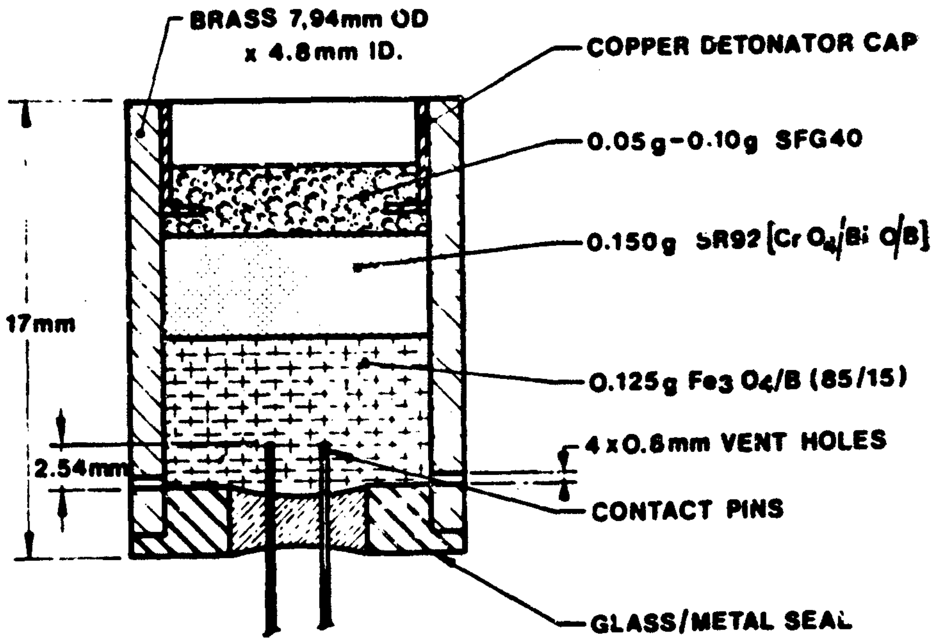
Function

1. On launching the Pyrotechnic Switch is ignited from hot gases.

2. After time delay the Pyrotechnic Switch closes, arming the circuit.

3. On impact the Impact Switch closes, igniting the Matchhead and the Explosive Train.

Fig. 1. Firing circuit utilising the Pyrotechnic Switch.



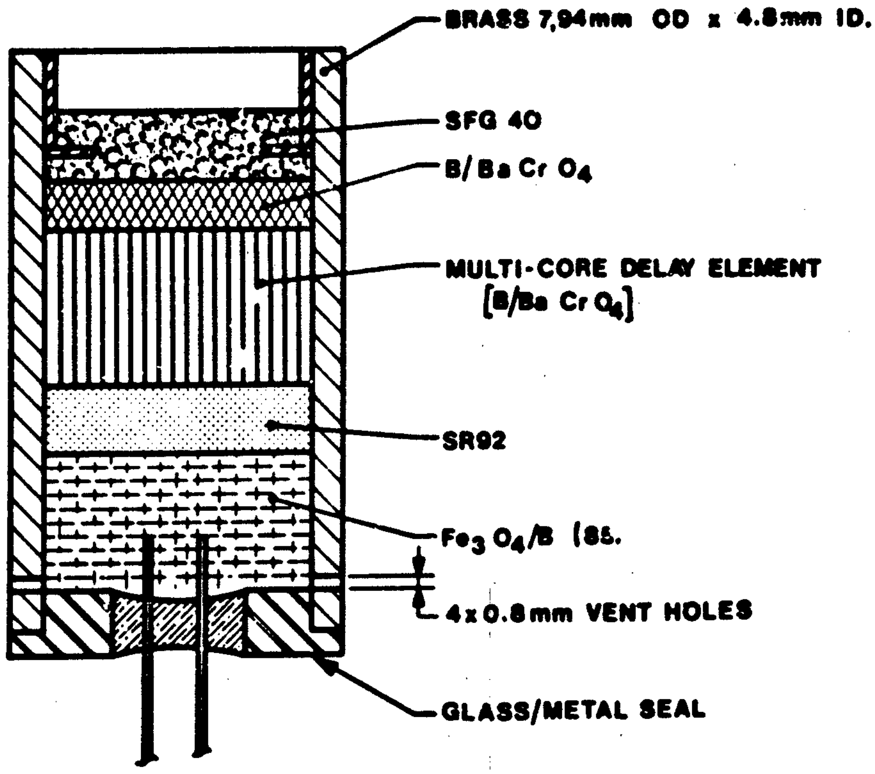
Function

1. On launching hot gases ignite the SFG 40.

2. After time delay the resistance across the contact pins drops from 130-180 kΩ to less than .1Ω.

3. Typical time delay 0.1 - 0.27 s. Longer time delays can be accommodated.

Fig. 2. Details of Pyrotechnic Switch.



Function

1. On launching hot gases ignite the SFG 40.

2. The pyrotechnic chain $B/BaCrO_4$ - 6 strand lead multicore (filled with $B/BaCrO_4$) - SR92 - B/Fe_3O_4 burns through.

3. Time delay governed by quantity of materials pressed and length of multicore selected.

Fig. 3. Pyrotechnic Switch with multicore delay.

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